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Sequestered Organic Carbon Stock in the Soils under Different Land Uses in Uttarakhand State of India

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Abstract

The Intergovernmental Panel on Climate Change identified creation and strengthening of carbon sinks in the soil as a clear option for increasing the removal of CO_2 from the atmosphere and has recognized soil organic carbon pool as one of the five major carbon pools for the land use, land use change and Forestry sector. Land is being used for different purposes like forestry, agriculture, agroforestry, pastures, horticulture, plantations, habitat etc. Land use and soil management practices can significantly influence soil organic carbon dynamics and carbon flux of the soil. A study was conducted to estimate the soil organic carbon (SOC) stock in the soils under forest, horticulture, agroforestry and grassland land uses in Uttarakhand state of India. Data revealed that maximum SOC pool was in the soils under grasslands (116.98 t ha^{-1}) followed by forest (74.56 t ha^{-1}), horticulture (51.71 t ha^{-1}) and agroforestry (25.92 t ha^{-1}). Maximum mitigation potential was observed under grassland (4.51) followed by forests (2.87). This indicates that soil under these land uses can hold organic carbon more than four times and nearly three times higher as compared to soil under agroforestry land uses. Results of one-way ANOVA indicates that the concentration of SOC stock between the different land uses was significantly different at 0.05 level (variance ratio, $F = 190.789$; $p < 0.05$). The maximum share of SOC stock in Uttarakhand was contributed by grassland (37.58%) followed by forests (23.91%), horticulture (16.58%) and the lowest share was of agroforestry (8.31%).

Keywords: Soil organic carbon pool, Agroforestry, Forests, Grasslands, Horticulture, Uttarakhand.

1. Introduction

Soil contains an important pool of active carbon that plays a major role in the global carbon cycle [1, 2]. Arnone and Korner [3] estimated that soil represented the largest depositories for fixing carbon in all ecosystems. Soils represent the largest terrestrial stock of carbon. The first 30 cm of soil holds 1500 Pg C in the world and 9 Pg C in India [4] . The build-up of each ton of soil organic matter removed 3.667 tons of CO_2 from the atmosphere [5]. Bulk of the carbon enters the ecosystem through the process of photosynthesis in the leaves. The litter received on floor undergoes mineralization and re-synthesis, by a biochemical process, to form humus. The soil organic carbon is thus stored for a long time in the form of humic substances and finally acts as sinks in soils [6]. The soils hold two to three times more carbon than the atmospheric CO_2 [7] and decline in soil organic carbon (SOC) has major implications for the maintenance of soil health. Land is being used for different purposes *viz.* for forestry, agriculture, agroforestry, pastures, horticulture, plantations, habitat etc. Land use and soil management practices can significantly influence soil organic carbon dynamics and carbon flux of the soil [8, 9]. Since every land-use change causes a disturbance of the long-termed adjusted balance of soil organic matter (SOM) supply and mineralization, self-restoration also leads to alterations in the SOM dynamics [10].

The Intergovernmental Panel on Climate Change (IPCC) identified creation and strengthening of carbon sinks in the soil as a clear option for increasing the removal of CO_2 from the atmosphere and has recognized soil organic carbon pool as one of the five major carbon pools for the land use, land use change and Forestry sector (LULUCF) (paragraph 21 of the annex to draft decision 16/CMP.1) [11]. It is mandatory for all signatory nations to the Kyoto protocol, to report soil organic carbon pool and changes from the LULUCF under National Communications to the United Nations Framework Convention on Climate Change (UNFCCC).

Accurate quantification of the SOC pool is necessary to ascertain the current status and evaluate the change in its status over a period of time. Laboratory analyses indicate carbon concentration in soils, but the soil layer thickness, bulk density and per cent of fragments > 2 mm must be known in order to estimate SOC storage [12]. Estimation of SOC stocks requires bulk density measurements. Variability in bulk density contributes to carbon stock uncertainty, in turn affecting how large a change in stock can be observed over time or space [13]. No systematic study has been undertaken to estimate the SOC pool in Uttarakhand state of India. Therefore, this study was undertaken to estimate SOC pool in different land uses, viz., forestry, grass land, horticulture and agroforestry by using the IPCC guidelines in all the 13 districts of the state. Information generated from this study can be used as a benchmark baseline for the studies pertaining to change in SOC stock, climate change, land management etc.

2. Materials and Methods

This study was conducted in whole of Uttarakhand state which forms part of the western Himalaya. It is located between 28° 43' – 31° 27' N latitudes and 77° 34' – 81° 02' E longitudes. Altitude of sampling sites varied from 213 – 4200 m above m s l under different land uses. The average annual rainfall of the state, as recorded is 1,547 mm. Since the input of organic matter is largely from aboveground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper profile is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances [14]. This layer is readily depleted by anthropogenic disturbances such as land use changes and cultivation. Therefore, soil organic carbon pool was estimated to the depth of 30 cm in this study.

Soil organic carbon stock in Uttarakhand was estimated in different land uses *viz.* forests, horticulture, agro-forestry and grasslands in all the thirteen districts of Uttarakhand. Stratified sampling design was adopted for selection of sites for soil sample collection. It was ensured that sampling points typically represent the study area. In forest land use, the sampling was carried out in natural forest, plantation forest and barren lands in forest area. In natural forests the soil samples were collected from all the existing forest covers *i.e*. spruce / fir, (*Picea smithiana/ Abies pindrow*), deodar (*Cedrus deodara*), quercus (*Quercus leucotrichophora*), kail (*Pinus wallichiana*), chir (*Pinus roxburghii*), sal (*Shorea robusta*) and miscellaneous forest. The tree plantations in forest land included cypress (*Cypress cashmeriana*), eucalyptus (*Eucalyptus spp*), khair (*Acacia catechu*), teak (*Tectona grandis*) and shisham (*Dalbergia sissoo*). In case of horticulture, the soil samples were collected from mango (*Mangifera indica*), guava (*Psidium guajava*), litchi (*Litchi chinensis*), apple (*Malus domestica*) and kinnow (*Citrus reticulate*) orchards. The wheat (*Triticum sativum*) – poplar (*Populus deltoids*) and sugar cane (*Sachharum offficinalis*) – poplar agroforestry models were the major agroforestry models in the state and were therefore, sampled. The grasslands extend over a wide range of altitude in the state and were categorized as below 2750m and above 2750m for the purpose of sampling.

At each sampling site in every land use/land cover, 5 soil samples were collected from 0 to 30 cm depth for soil organic carbon estimation and two separate samples were collected for bulk density and coarse fragment estimation. In total, little over 3,925 soil samples were collected including 3,148 from forests, 532 from horticulture, 147 from agroforestry 109 from grassland for soil organic carbon, bulk density and coarse fragments estimation. Bulk density at every site was estimated by standard core method [15] which is necessary to convert organic carbon content on per unit area basis [16]. Soil organic carbon was estimated by standard Walkley and Black [17] method. Amount of coarse fragments were estimated in each sample collected from different forests and deducted from the soil weight to get an accurate soil weight on unit area basis for SOC pool estimation. All the methods used in this study are in accordance to Ravindranath and Ostwald [18].

The data for the SOC stocks was calculated by using the following equation as suggested by IPCC Good Practice Guidance for LULUCF [19]:

Equation for SOC

$$SOC = \sum_{Horizon=1}^{Horizon=n} SOC_{horizon} = \sum_{Horizon=1}^{Horizon=n} ([SOC] * \text{Bulk density} * \text{depth} * (1 - \text{C frag}) * 10)$$

Where,
SOC = Representative soil organic carbon content for the forest type and soil of interest, tons C ha^{-1}
$SOC_{horizon}$ = Soil organic carbon content for a constituent soil horizon, tons C ha^{-1}
[SOC] = Concentration of SOC in a given soil mass obtained from analysis, g C $(kg\ soil)^{-1}$
Bulk density = Soil mass per sample volume, tons soil m^{-3} (equivalent to Mg m^{-3})
Depth = Horizon depth or thickness of soil layer, m
C Frag = % volume of coarse fragments / 100, dimensionless

Appropriate statistical analysis was carried out for obtaining standard error, standard deviation and ANOVA for estimating the differences in the means of soil organic carbon store under different vegetation covers as well as under different land uses by using SPSS 15.0.0 software [20].

3. Results and Discussion

3.1. SOC Pool under Forest Lands

There are 3 different situations in forest lands i.e. natural forest, tree plantation and barren unproductive lands. The SOC was estimated in all of them. In natural forests, the SOC was estimated under different dominant species and maximum SOC stock was found under silver fir & spruce (140.76 t ha^{-1}) followed by deodar (118.09 t ha^{-1}), quercus (96.44 t ha^{-1}), kail (67.66 t ha^{-1}), chir (61.10 t ha^{-1}), miscellaneous (58.95 t ha^{-1}) and sal forest (58.45 t ha^{-1}).

Results of one-way ANOVA indicates that difference between the SOC pools was significant at 0.05 level (Variance ratio, F = 214.857; $p < 0.05$) between different natural forests.

The estimates of SOC pools, under plantation forests i.e. the plantation on the areas which are under control of State Forests Department as per Uttarakhand Forest Statistics 2009 – 2010., revealed that soils under cypress plantation held maximum SOC *i.e.* 66.32 t ha^{-1}, followed by eucalyptus 42.73 t ha^{-1}, khair 41.67 t ha^{-1}, teak 40.71 t ha^{-1} and shisham 32.96 t ha^{-1}. The one-way ANOVA indicates that SOC pool between the different planted forests was significantly different at 0.05 level (Variance ratio, F = 11.357; $p < 0.05$). The SOC stock was comparatively lowest in unproductive barren lands *i.e.* 27.73 t ha^{-1}. Trees play an important role in soil C sequestration as they promote more C storage in soils and the biomass [21]. The conversion of about 28 million hectares of farmland to tree plantation led to a large accumulation of biomass carbon and SOC (96.4 g cm^{-2} yr^{-1}) in the surface soil layer [22]. Chang, et al. [23] also reported the enrichment of soils with organic carbon as a consequence of *Robinia pseudoacacia* plantation establishment on cropland. However, SOC pool was higher under natural forests as compared to planted forests. This may be because of higher litter fall produced by natural forests.

Out of total SOC stock in the forest lands of Uttarakhand state, 1.78% (2.67 million tons) was stored in plantation forests, 10.02% (15.01 million tons) in unproductive barren lands and 88.19% (132.05 million tons) was in the natural forests. Total SOC stock under 24,414.80 km^2 forest land of Uttarakhand was 149.73 million tons which is equivalent to 499.60 million tons of carbon dioxide.

3.2. SOC Pool in Horticulture Land Use

In horticulture land use, the highest SOC stock was estimated under apple orchards (80.81 t ha^{-1}) followed by mango (50.70 t ha^{-1}), citrus (47.55 t ha^{-1}), litchi (44.93 t ha^{-1}) and guava (40.21 t ha^{-1}). One-way ANOVA indicates that SOC stocks between the orchards were significantly different at 0.05 level (Variance ratio, F = 19.433; $p < 0.05$). Over all, the soils under horticulture land use in Uttarakhand contain 10.75 million tons of organic carbon stock which is equivalent to 39.42 million tons of carbon dioxide.

3.3. SOC Pool under Agroforestry Land Use

Agroforestry land use was mainly available in Hardwar and Udham Singh Nagar districts of the state. The SOC stock under sugarcane – poplar (33.48 t ha^{-1}) model was higher in comparison to wheat – poplar (24.81 t ha^{-1}). Sugarcane – poplar agroforestry model had 34.95 % higher SOC pool as compared to wheat – poplar. The SOC pool between the two models were significantly different at 0.05 level (variance ratio, F = 5.308; $p < 0.05$). The findings of Gaur and Gupta [24] corroborate our results who reported that the organic carbon pool in the soils under *Populus deltoides* based agroforestry systems varies from 22.31 to 27.82 Mg C ha^{-1}at Kalesar and 19.63 to 30.11 Mg C ha^{-1}at Salimpur in Haryana state of India.

3.4. SOC Pool under Grasslands

Grasslands were mainly available in Rudrapryag, Chamoli, Uttarkashi, Dehra Dun and Nainital districts of the state. The soil organic carbon stock in grasslands was estimated from low altitudes to alpine pastures. The SOC in grasslands situated below 2750 m altitude was estimated 86.58 t ha^{-1} while the SOC stock above 2750 m, was 143.76 t ha^{-1}. SOC pool above 2750 m altitude was 66.05% higher as compared to its value below 2750 m altitude. One-way ANOVA indicated that SOC pool between the two groups (below 2750 m and above 2750 m altitudes) were significantly different at the 0.05 level (variance ratio, F = 28.659; $p < 0.05$). Rawat [25] reported that SOC and potassium were positively correlated with the altitudinal gradient. Soil organic carbon content was also found to be strongly correlated with elevation in the grasslands of mountainous French region [26]. The average SOC pool in the grasslands of Uttarakhand is 116.98 t ha^{-1} and the permanent pastures extend over an area of 2,28,900 ha [27]. Therefore, 26.77 million tons of SOC pool was contained by the grasslands in Uttarakhand state which is equivalent to 98.16 million tons of carbon dioxide. Conant, et al. [28] also reported that grassland soils are rich in organic carbon and contain an extensive fibrous root system that creates an environment ideal for soil microbial activity.

Table-1. Soil organic carbon pool under different land uses in Uttarakhand (up to 30 cm)

Sl. No.	Vegetation Cover	SOC Pool (t/ha)	Mitigation Potential	SE	Confidence Interval (t ha^{-1}) (α= 0.05)	
					Upper bound	Lower bound
1	Grassland	116.98^{a} ± 55.1428	4.51	6.20	104.63	129.33
2	Forests*	74.56^{b} ± 38.0539	2.87	0.80	72.99	76.14
3	Horticulture	51.71^{c} ± 30.8001	1.99	1.56	48.64	54.78
4	Agroforestry	25.92^{d} ± 13.4144	1.00	1.28	23.37	28.47

Same alphabets represent statistically at par group; * This is the average of natural forests in Uttarakhand

3.5. Total SOC Pool

The combined results of the estimated SOC pools under forests, horticulture, agroforestry and grassland of Uttarakhand are presented in Table 1. The maximum SOC stock was found under grasslands *i.e.* 116.98 t ha^{-1} (CI 104.63 – 129.33) followed by forests 74.56 t ha^{-1} (CI 72.99 – 76.14), horticultures 51.71 t ha^{-1} (CI 48.64 – 54.78) and agroforestry land use 25.92 t ha^{-1} (CI 23.37 – 28.47). Higher SOC pool in grassland could be explained by the inclusion of alpine grassland which contains SOC stock as high as 154 t ha^{-1}.

The SOC pool under grassland was 56.89% higher as compared to forests while it was 126.22% and 351.31% higher as compared to horticulture and agroforestry land uses, respectively. The SOC stock under forests was 44.19% higher in comparison to the SOC pool under horticulture and 187.65% higher as compared to agroforestry land uses. The SOC stock under horticulture land use was 99.50% higher as compared to agroforestry.

The proportion of SOC pool shared by individual land uses is presented in figure 1. The highest share was contributed by grassland (37.58%) followed by forests (23.91%), horticulture (16.58%), plantations (13.67%) and the lowest share was of agroforestry (8.31%).

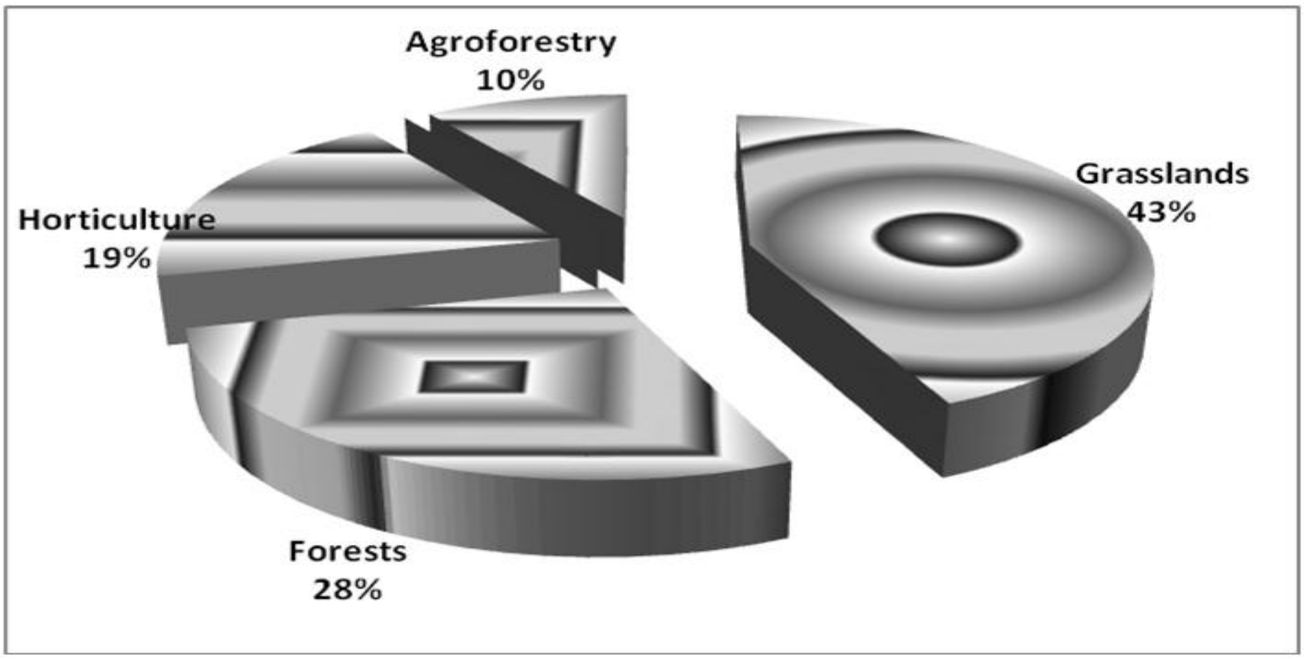

Fig-1. Proportion of total SOC pool shared by different Land uses

SOC pool between the different land uses was significantly different at 0.05 level (variance ratio, F = 190.789; $p < 0.05$). SOC stock under grassland was significantly different from the SOC stock under all other land uses, *viz.*, forests, horticulture and agroforestry. SOC stock under horticulture was also statistically significantly different from the SOC stock under agroforestry and grass lands (Table 2).

Table-2. Statistically significant mean differences on the basis of CD (LSD)

Sl. No.	Vegetation	Mean Difference	P value
1	Grassland Vs Forest	42.4141*	0.000
2	Grassland Vs Horticulture	65.2701*	0.000
3	Grassland Vs Agroforestry	91.0581*	0.000
4	Forests Vs Horticulture	22.8560*	0.000
5	Forests Vs Agroforestry	48.6440*	0.000
6	Horticulture Vs Agroforestry	25.7880*	0.000

* Mean difference is significant at the 0.05 level

Thus there are significant differences in SOC stock under different land uses. Wang, et al. [29] also reported that in the Upstream Watershed of Miyun Reservoir, North China, both SOC contents in natural secondary forests and grasslands were much higher than in plantations and croplands. Gua and Gifford [30] reported that soil carbon stocks decline after land use change from native forest to plantation (- 13%), native forest to crop land (- 42%) and pasture to crop land (- 59%) while soil carbon stocks increased after land use change from crop to pasture (+ 19 %), crop to plantation (+ 18%) and crop to secondary forests (+ 53%). Six and Jastrow [31] and Baker [32] also reported that soil organic matter may change depending on numerous factors, including land use and management practice. Soil organic carbon is sensitive to impact of anthropogenic activities. The highest SOC content was found in natural undisturbed forest, whereas lowest SOC was observed in conventionally- tilled, continuously-cropped plots [33, 34]. In general, the forest soils have much higher soil carbon store in comparison to agroforestry, agriculture and barren land. Agroforestry has 37.28% higher SOC store in comparison to agriculture and 121% higher than in barren land [35, 36]. The accumulation of carbon in the soil is strongly influenced by biological factors, such as vegetation which controls the amount, quality and distribution of litter fall and associated microbial communities [37].

The mitigation potential of the soils under different land uses was estimated by taking the value of SOC stock in Agroforestry as 1 as this land use has the lowest SOC stock [38]. Maximum mitigation potential was observed under grassland (4.51) followed by forests (2.87). This indicates that these land uses can hold organic carbon more than four times and nearly three times higher as compared to agroforestry land use. Horticulture can store SOC stock two times more than the agroforestry land use as its mitigation potential is 1.99. Standard error varied from 0.80 (under forests) to 6.20 (under grassland). Little higher standard error in grassland is because of grater variation in data as it was spread in wide altitudinal range and samples were collected from 1000 m to more than 4000 m above mean sea level.

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